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PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

Express Mail Label No. EU797833732US

INVENTOR(S)

Given Name (first and middle [if any])	Family Name or Surname	Residence (City and either State or Foreign Country)
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☐ *Additional inventors are being named on the _______ separately numbered sheets attached hereto*

TITLE OF THE INVENTION (500 characters max)

METHOD AND APPARATUS FOR QUANTIFYING VISUAL SHOWTHROUGH OF PRINTED IMAGES ON THE REVERSE OF PLANAR OBJECTS

Direct all correspondence to: **CORRESPONDENCE ADDRESS**

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ENCLOSED APPLICATION PARTS *(check all that apply)*

☑ Specification *Number of Pages* 25 ☐ CD(s), Number

☑ Drawing(s) *Number of Sheets* 13 ☑ Other (specify)

☐ Application Data Sheet. See 37 CFR 1.76

METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION FOR PATENT

☐ Applicant claims small entity status. See 37 CFR 1.27.
☐ A check or money order is enclosed to cover the filing fees
☑ The Commissioner is hereby authorized to charge filing fees or credit any overpayment to Deposit Account Number: **04-1928**
☐ Payment by credit card. Form PTO-2038 is attached.

FILING FEE AMOUNT ($)

The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.
☐ No.
☐ Yes, the name of the U.S. Government agency and the Government contract number are: ____________

Respectfully submitted,

SIGNATURE Rebecca Tulloch

Date 4/7/03

TYPED or PRINTED NAME REBECCA W. TULLOCH

REGISTRATION NO. *(if appropriate)* 36,297

Docket Number: CL2125 US PRV

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USE ONLY FOR FILING A PROVISIONAL APPLICATION FOR PATENT

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FEE TRANSMITTAL for FY 2003

Patent fees are subject to annual revision.

☐ Applicant claims small entity status. See 37 CFR 1.27

TOTAL AMOUNT OF PAYMENT ($) 160.00

Complete if Known	
Application Number	
Filing Date	
First Named Inventor	BARRY RUBIN
Examiner Name	
Art Unit	
Attorney Docket No.	CL2125 US PRV

METHOD OF PAYMENT *(check all that apply)*

☐ Check ☐ Credit card ☐ Money Order ☐ Other ☐ None

☑ Deposit Account:

Deposit Account Number: 04-1928

Deposit Account Name: E. I. du Pont de Nemours and Company

The Commissioner is authorized to: *(check all that apply)*

☑ Charge fee(s) indicated below ☑ Credit any overpayments

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FEE CALCULATION

1. BASIC FILING FEE

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
1001	750	2001	375	Utility filing fee	
1002	330	2002	165	Design filing fee	
1003	520	2003	260	Plant filing fee	
1004	750	2004	375	Reissue filing fee	
1005	160	2005	80	Provisional filing fee	160.00

SUBTOTAL (1) ($) 160.00

2. EXTRA CLAIM FEES FOR UTILITY AND REISSUE

		Extra Claims		Fee from below		Fee Paid
Total Claims	-20** =		X	18.00	=	
Independent Claims	- 3** =		X	84.00	=	
Multiple Dependent ☐ YES				280.00	=	

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description
1202	18	2202	9	Claims in excess of 20
1201	84	2201	42	Independent claims in excess of 3
1203	280	2203	140	Multiple dependent claim, if not paid
1204	84	2204	42	** Reissue independent claims over original patent
1205	18	2205	9	** Reissue claims in excess of 20 and over original patent

SUBTOTAL (2) ($) 0.00

**or number previously paid, if greater; For Reissues, see above

FEE CALCULATION (continued)

3. ADDITIONAL FEES

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
1051	130	2051	65	Surcharge - late filing fee or oath	
1052	50	2052	25	Surcharge - late provisional filing fee or cover sheet	
1053	130	1053	130	Non-English specification	
1812	2,520	1812	2,520	For filing a request for *ex parte* reexamination	
1804	920*	1804	920*	Requesting publication of SIR prior to Examiner action	
1805	1,840*	1805	1,840*	Requesting publication of SIR after Examiner action	
1251	110	2251	55	Extension for reply within first month	
1252	410	2252	205	Extension for reply within second month	
1253	930	2253	465	Extension for reply within third month	
1254	1,450	2254	725	Extension for reply within fourth month	
1255	1,970	2255	985	Extension for reply within fifth month	
1401	320	2401	160	Notice of Appeal	
1402	320	2402	160	Filing a brief in support of an appeal	
1403	280	2403	140	Request for oral hearing	
1451	1,510	1451	1,510	Petition to institute a public use proceeding	
1452	110	2452	55	Petition to revive - unavoidable	
1453	1,300	2453	650	Petition to revive - unintentional	
1501	1,300	2501	650	Utility issue fee (or reissue)	
1502	470	2502	235	Design issue fee	
1503	630	2503	315	Plant issue fee	
1460	130	1460	130	Petitions to the Commissioner	
1807	50	1807	50	Processing fee under 37 CFR 1.17(q)	
1806	180	1806	180	Submission of Information Disclosure Stmt	
8021	40	8021	40	Recording each patent assignment per property (times number of properties)	
1809	750	2809	375	Filing a submission after final rejection (37 CFR 1.129(a))	
1810	750	2810	375	For each additional invention to be examined (37 CFR 1.129(b))	
1801	750	2801	375	Request for Continued Examination (RCE)	
1802	900	1802	900	Request for expedited examination of a design application	

Other fee (specify) ____

*Reduced by Basic Filing Fee Paid

SUBTOTAL (3) ($) 0.00

SUBMITTED BY

(Complete *(if applicable)*)

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CL2125 US PRV

TITLE OF INVENTION

METHOD AND APPARATUS FOR QUANTIFYING VISUAL SHOWTHROUGH OF PRINTED IMAGES ON THE REVERSE OF PLANAR OBJECTS

BACKGROUND OF THE INVENTION

For planar printing substrates, such as paper products, there is a need for hiding power and visual appearance uniformity. Optical opacifiers, such as titanium dioxide (TiO_2), are used to provide these attributes. A highly uniform front surface appearance is desired in these products, even when there is printing on the reverse surface of the product. The degree to which images printed on the reverse surface can be seen when the front surface is illuminated and viewed is known as "showthrough". It is well-known that the thickness and the inherent opacity of the product, as well as the penetration depth of the ink printed on the reverse surface, affect the degree of showthrough.

Showthrough may be evaluated by trained human operators who make subjective ratings of the surface appearance based on visual observations of the front surface under controlled lighting conditions. Visual ratings by a number of human observers are typically employed to establish a uniformity scale that serves as an evaluation criterion. Opacity measuring instruments, known as opacimeters, have been traditionally utilized to quantify the degree of showthrough within a single small region on the surface. A standard measurement protocol, using such an instrument, is set forth in Technical Association of the Pulp and Paper Industry (TAPPI) standard T-425 om 01, entitled "Opacity of Paper (15/d Geometry, Illuminant A/2 Degrees, 89% Reflectance Backing and Paper Backing)". Measurements made with such instruments, however, do not provide a direct measure of human perception of showthrough, particularly when a patterned, image, or indicia, is printed on the reverse side of the product. An automated imaging system and method, such as that of the present invention, may be evaluated against such a criterion.

For many surfaces, particularly heavier weight papers, the reflectance variation to be quantified is quite small. The actual reflectance variation due to showthrough of a paper surface may be less than the variation in apparent reflectance (shading) caused by nonuniformity of illumination of the surface. The reflectance variation due to showthrough may even be less than the nonuniformity of camera response across an image of the surface.

Since the uniformity of a typical reflectance reference standard is comparable to the uniformity of some of the paper samples to be evaluated, prior art background correction techniques used in image processing, such as that of U.S. Patent 4,656,663, are usually inadequate. Overall lightness (average reflectance) differences that exist between the paper samples necessitates that the measurement of showthrough be independent of overall lightness. Because of these factors, the prior art methods do not produce accurate, reproducible results. A recent prior art method for quantifying visual appearance uniformity of planar surfaces of opaque objects is described in U.S. Patent 6,438,256 (assigned to the assignee of the present invention). This method, however, does not address the need for assessing the visual showthrough of printed images on the reverse side of a sheet of paper.

SUMMARY OF THE INVENTION

The present invention is an improved method for measuring the degree to which a printed image on a first side of a sheet is visible when illuminating and viewing a second side of the sheet, the method comprising:

a) creating a calibration image of a reference object containing no image;

b) determining an average gray level of the reference object and adjusting;

c) illuminating the sheet at an intensity the same as that used to create the calibration image and creating an image of the sheet;

d) measuring the ratio of the pixel intensities of the image of the sheet with the corresponding pixel intensities of the calibration image;

e) calculating a mean value of the ratios of the pixel intensities.

Stated in more detail, the present invention is an improved image analysis method for characterizing the showthrough of a printed image on the reverse surface of a substantially planar object having a reflective front surface, by measuring the optical reflectance of the front surface. The method includes the steps of:

a) uniformly illuminating, with a diffuse light source, the front surface of a reference object, said reference object having no image on its reverse, and creating a calibration image of the reference object, comprising the steps of ;

(1) creating a frame-averaged dark current image representing the response of the photodetector array in the absence of light;

(2) illuminating the front surface of a reference object with the diffuse light source, the output of the light source being set to an initial illumination output level;

(3) creating a frame-averaged image of the front surface of the reference object by:

(i) imaging the light reflected from the front surface of the reference object onto a photodetector array to create an electrical signal representative of the image;

(ii) digitizing the electrical signal using an analog to digital converter;

(iii) storing the digitized representation of the image as an array of picture elements in a memory;

(4) determining the average gray level in the image of the reference object;

(5) adjusting the illumination level by adjusting the output of the light source and repeating steps (3) and (4) until the average light level reflected by the front surface of the reference object causes an average gray level in the image of step (3) to be within a predetermined range of a predetermined value within the dynamic range of the analog to digital converter, thereby establishing a predetermined illumination level;

(6) creating a frame-averaged reference image of the front surface of the reference object;

(7) creating a dark-current corrected reference image by subtracting the frame-averaged dark current image of step (3) from the frame-averaged reference image of step (6) on a pixel by pixel basis and storing the resulting image in the memory;

(b) uniformly illuminating, with the diffuse light source at the predetermined illumination level, the front surface of a sample object having a printed image on the reverse surface;

(c) creating a frame-averaged image of the front surface of the sample object, by:

(1) imaging the light reflected from the front surface onto a photodetector array to create an electrical signal representative of the image;

(2) digitizing the electrical signal using an analog to digital converter;

(3) storing the digitized representation of the image as an array of picture elements in a memory, and

(d) analyzing the digitized representation, the analyzing step comprising:

(1) creating a dark-current corrected image of the front surface of the sample object by subtracting the frame-averaged dark current image of step (a) (1) from the frame-averaged image of the front surface of step (c) (3) on a pixel by pixel basis and storing the resulting image in the memory;

(2) calculating a ratio of the image of step (e) (1) with the image of step (a) (7) on a pixel by pixel basis; and

(3) calculating a mean value of the ratios of the pixels.

The method of the present invention is believed to be advantageous over the prior art in several ways. For each type paper to be characterized, the illumination level is set by creating a reference or calibration image utilizing a plurality of unprinted sheets of that type of paper in a stack or pad sufficiently thick so that all of the light that penetrates through the top of the paper stack is reflected or absorbed.

Such a stack represents an "optically infinitely thick" stack, and if additional sheets are added to the stack, no change in overall reflectance results. An image of the stack is created and the illumination level is adjusted so that the mean pixel value is within a predetermined narrow range within the overall dynamic range of the analog to digital converter, typically near the center of the dynamic range. This insures that subsequent images of single sheets of each type of paper will have a predetermined average gray level value within a predetermined range within the overall dynamic range of the digitization.

The output of the light source need only be stable over the period of time during which the images of a group of samples is being acquired, typically only a few seconds per image. The showthrough measurement is independent of overall lightness differences between samples and is independent of illumination intensity variations over the field of view.

The illumination assembly provides a diffuse source of light to the sheet being measured, with the illumination intensity being uniform over the area being imaged. A hemispherical dome, coated with a diffusely reflecting coating is illuminated around its perimeter by a circular array of white light emitting diodes.

The images are also corrected for camera photodetector dark current. This substantially removes contributions of the camera dark current from the measured gray level variation across the image. Since a dark current image may be captured and stored as often as desired, the uniformity measurement is effectively insensitive to CCD photodetector dark current spatial distribution variations over time, which may be related to temperature changes or aging effects in the camera CCD or electronics.

BRIEF DESCRIPTION OF THE FIGURES

Figure 1 shows a block diagram of a system for measuring showthrough of an image on a sheet;

Figure 2 is a pictorial view of an arrangement for measuring showthrough of an image on a sheet;

Figure 3A shows an exploded perspective view of an unprinted sheet illuminated from a first side, the sheet being mounted on a black surface, with the illuminator shown in section;

Figure 3B shows an exploded perspective view of a printed sheet illuminated from a first side, the sheet having a printed image on a second side, the sheet being mounted on a black surface, with the illuminator shown in section;

Figure 4 shows an exploded perspective view of a stack or pad of sheets used for measuring the reflectance of an "infinite pad" of unprinted sheets, with the illuminator shown in section;

Figure 5A shows a sectional view of a light source arrangement for illuminating a sheet to be measured;

Figure 5B shows a plan view, looking upward, of the diffuse reflector and photodetector within the interior of the light source;

Figure 6 shows an enlarged view of the photodetector used to control the illumination level;

Figure 7 is a block diagram illustrating the overall method of the present invention;

Figures 8A and 8B show a block diagram illustrating a method of adjusting the illumination level of the sample;

Figure 9 is a plot showing the correlation of the output of the inventive method plotted against the opacity values produced by method of the TAPPI Standard T-425.

Figure 10 is a plot showing the response of the photopic filter.

DETAILED DESCRIPTION OF THE INVENTION

Showthrough Measurement Principles

When evaluating the opacity of printing substrates such as paper or film it is necessary to quantify the visibility of a printed image on the backside of a printed page. A parameter called Showthrough Value, or DSV, is a measure of the visibility of a printed image on the backside of a printed page. A DSV of zero indicates a completely opaque page, i.e. the presence of printing on the back of the sheet is not detectable. A DSV of

100 indicates that the page is completely transparent or that the ink from the printing has bled through the page.

The contribution of ink penetration to print showthrough, called Strike-In, can be calculated by taking the difference between Printed and Unprinted DSV.

Printed DSV = 100 – Ro'/Rinf

Unprinted DSV = 100 – Ro/Rinf

Strike-In = Printed DSV – Unprinted DSV

Where:

Ro - Reflectance of a single unprinted sheet on a black backing.

Ro' - Reflectance of a single printed sheet with the print opposite the illuminated side or a black backing.

Rinf - Reflectance of an infinite pad of unprinted sheets. An infinite pad is defined as a pad (or stack) of sufficient thickness such that doubling the thickness does not change the reflectance reading.

The equations for DSV contain a term that is a ratio of a single sheet reflectance to a reference reflectance, in this case Rinf. This term is a called a contrast ratio and is a measure of the opacity of the sheet. Dividing the single sheet reflectance by a reference reflectance removes the effect of surface reflectivity (also called sheet brightness) from the DSV reading. The contrast ratio is subtracted from 100 to give a reading that increases with increasing showthrough. A sheet with no showthrough gives a zero DSV reading.

Apparatus

The apparatus 10 of the present invention, as seen in Figure 1, comprises a planar object imaging assembly 12, also referred to as the sample imaging assembly, and an associated computerized image processor 14. The planar object imaging assembly 12, best seen in Figures 2, 3A, 3B, 4, and 5A, comprises a light-tight housing 20 in which

are mounted a sample holding fixture 30, an illumination assembly 40, a CCD camera 50, a photographic lens 60 and an optical filter assembly 70 and an optional photopic filter assembly 80.

The housing 20 comprises a generally rectangular enclosure (best seen in Figure 5A) having a bottom wall 22BW, side walls 22SW, and an interior dividing wall 22W, upon which is mounted a top hemispherical dome 22D (Figures 3A, 3B, 4, and 5A). The sample holding fixture 30 comprises a generally planar clamping device 32 that holds a sample S flat in a holding frame 34 in an opening in the interior dividing wall 22W of the housing 20. The clamping device 32 is urged against the frame 34 by a spring 36 (Figure 5A). The frame 34 defines a sample plane P. The frame 34 has a black upper surface 34B that contacts the sample S.

The illumination assembly 40, which illuminates the planar sample S, comprises a circular array 42A of light sources 42 mounted within a dome 22D. The light sources 42, which are preferably light emitting diodes, are mounted ,just above the interior dividing wall 22W, i.e., at the equatorial position of the hemisphere. The inner surface 22S of the hemisphere of the dome 22D is coated with a diffusely reflecting coating.

A portion 22B of the interior surface of the hemisphere adjacent the polar opening has a substantially non-reflecting region so that specular reflections from the sample object S are not imaged by the imaging assembly. The shape of the portion 22B corresponds to the area of the sample object being imaged. This feature insures that only diffusely reflected light is imaged by the camera 50. This becomes particularly important when analyzing planar objects having a glossy surface, since specular reflections from such a glossy surface could cause artifacts in the image and degrade the accuracy of the Showthrough measurement.

The circular array of light emitting diodes, 42 are positioned above the plane P of the sample S and are symmetrically disposed about the center C of the sample S in a circular array 42A within an annular area approximately seventy to ninety percent of the diameter of the hemispherical dome 22D. Figure 5B depicts a portion of a typical circular array 42A. As seen in Figure 1, the light emitting diodes 42 are divided into N groups, 42-1 through 42-N, typically twenty-four groups of five LEDs

in each group, for a total of one hundred twenty LEDs. Suitable LEDs are manufactured by Nichia and are sold as part number NSPW 500-BS. Each group is wired in series with a current limiting resistor. Each of the groups is then wired in parallel with the other groups and connected to a constant current source 44.

Before the illumination assembly 40 is put into use a voltage verification test is performed. The LEDs are wired together and then low voltage is applied and adjusted until all the lamps begin to turn on. Typically the turn-on voltage is 11-12 volts DC. If a few lamps turn on before the others, then those lamps are replaced. This insures that all the lamps must turn on evenly and produce substantially uniform light levels. A commercially illumination assembly, available from Advance Illuminator, Inc. of Pochester, VT, wired as described above, has been found suitable. As seen in Figure 1, the constant current source 44 is controlled by a photodetector accessory 48 (enlarged view in Figure 4), such as a photodetector from Advanced Photonix, Inc. of Hopkinton, MA. The photodetector 48 monitors the light from the LEDs that has been diffusely reflected from the surface 22S (arrows 204) and provides a feedback signal to the light controller 44 to produce a precise output light level.

The interior wall 22W and the inside surface 22S of the hemispherical dome 22D, such as one available from Labsphere, Inc. of North Sutton, NH, define a sample illumination chamber 26. The interior surfaces of the walls of the sample illumination chamber 26 are coated with a high reflectivity, diffusely reflecting material, such as a flat white paint, to provide a uniform illumination level to the surface of the sample S. A preferred coating is sold under the trade name Duraflect, a proprietary water resistant and durable white reflectance coating, having a reflectivity at a wavelength of 600 nanometers (nm) of 94 - 96% and an effective spectral range: 350 - 1200 nm, available from Labsphere, Inc.

The dome 22D has an opening at the top (e.g., at the polar position) to accommodate a camera 50. The camera 50, the photographic lens 60, and the filter assemblies 70, 80 are mounted on the top of the dome 22T so that the photographic lens 60 projects an image of the sample plane P onto a CCD photodetector array 52 within the camera 50.

The lens 60 is mounted a fixed distance above the sample plane P, in accordance with the focal length of the lens. A suitable lens is a Schneider 23 mm focal length, f/2.3 which is mounted about 16 centimeters (6.325 inches) above the sample plane P.

The optical filter assembly 70 comprises a commercial haze filter mounted on the front of the lens 60 and the camera 50, and serves primarily to mechanically protect the lens 60. A filter assembly 80 may be used to control the spectral response of the system so that the image analysis method utilizes information in a predetermined spectral region, such as to match the spectral response of the human eye. A filter available from Barr Associates of Westford MA has been found satisfactory for such purpose. This filter 80 is typically mounted between the lens 60 and the CCD camera 50. A filter 80 having a maximum transmission of greater than 95 percent, a center wavelength of 550 nm +/- 5 nm and half-power points of 510 nm (+/-5 nm) and 610 nm (+/-5 nm) respectively, results in a system spectral response that approximates the response of the human eye.

The camera 50, such as model KP-M1 video camera, available from Hitachi Denshi America, Ltd. of Woodbury, NY, has an associated camera power supply 56. The camera 50 comprises a CCD photodetector array 52 and associated control and interface electronics 54, is mounted vertically with the CCD photodetector array 52 positioned so that the sample plane P is imaged by the lens 60 onto the CCD photodetector. The photographic lens 60 is typically set with its aperture at about f/8. A field of view of about 7 centimeters by 5 centimeters (2.8 inch x 2.0 inch) on the sample S is typically imaged.

Video images generated by the camera 50 are transmitted by a cable 16 to the computerized image processor 14. The computerized image processor 14 may comprise a Broadax Systems, Inc. (BSI) model PC-ATX-N9T12-15 Portable Computer. This computer comprises a display device D, such as a 15.4 inch TFT 1280x1024 LCD screen with analog-to-digital video signal converter; integrated keyboard with touch pad, built-in speakers, 300 Watt ATX power supply; two 5.25" vertical, two 3.5" horizontal open, one hidden 3.5" drive bays; and wheeled carrying

bag w/retractable handle. Standard Configuration Includes an ATX motherboard, an Intel Pentium III 733MHz CPU, Random Access Memory (RAM) 14R comprising 128MB SDRAM, magnetic storage devices 14M comprising a 10GB EIDE hard drive, a 1.44MB floppy drive, a 48X EIDE CD-ROM drive, a graphics module G comprising an ATI 8MB AGP SVGA card. Also included are a local area network module LAN, comprising a 3COM #3C905-TX 10/100BT LAN (PCI), an Iomega internal 250MB Zip drive (EIDE) 14Z and operating system software such as Microsoft's Windows 2000 Professional. Peripheral devices include a National Instruments Corp. model PCI 1409 multi-channel monochrome frame grabber 100 (National part number 778200-01), model PCI 6503 digital I/O card 120 (National part number 777690-01), and associated software such as IMAQ Vision for Labview (part number 778044-01).

For clarity of illustration light rays in Figures 3A, 3B and 4 are shown as arrows having an arrowhead with an open outline. At any given point only three or four arrows are shown. Arrowheads diverging from a point represent a cone of light. converging on a point representing diffusely reflected light, with the arrowheads converging. Figure 3A shows an exploded perspective view of an unprinted sheet S illuminated from a first side, the sheet being mounted on a black surface 34B. Figure 3A is exploded for clarity, but as may be appreciated from viewing the sectional view Figure 5A, the sheet S is in direct contact with the black surface 34B. The illuminating dome 22D and the light sources 42 are shown in section. The arrows 202 represent light rays emitted from the light sources 42. After diffusely reflecting from the interior surface 22S of dome 22D, the light arrives at the sheet, as depicted by arrows 206. The light rays reflected by the surface of the sheet are depicted by arrows 208.

Figure 3B shows an exploded perspective view of a printed sheet S_p illuminated from a first side, the sheet having a printed image (the word "IMAGE" depicted in reverse) on a second side, the sheet S_p being mounted on a black surface 34B. The illuminating dome 22D and the light sources 42 are shown in section. The arrows 202 represent light rays emitted from the light sources 42. After diffusely reflecting from the interior surface 22S of dome 22D, the light arrives at the sheet, as depicted by

arrows 206. The light reflected by the surface of the sheet S_p outside the area of the printed image is depicted by arrows 210. The light reflected by the surface of the sheet S_p within the area of the printed image is depicted by arrows 212.

Figure 4 shows an exploded perspective view of a stack or pad of unprinted sheets S-S used for measuring the reflectance of an "infinite pad" of unprinted sheets. The illuminating dome 22D and the light sources 42 are shown in section. The arrows 202 show the light emitted from the light sources 42. After diffusely reflecting from the interior surface 22S of dome 22D, the light arrives at the sheet, as depicted by arrows 206. The light reflected by the surface of the sheet is depicted by arrows 214.

Video images, typically measuring 640 pixels wide by 480 pixels high, are digitized by an eight-bit (256 gray levels) analog to digital (A/D) converter in the frame grabber 100 and are stored in a suitable memory device. A black reference level B and a white reference level W, which are software selectable, are used to control the upper and lower A/D voltages within the frame grabber 100. These voltages determine the range of input voltages from the camera 50 which get mapped to the 256 gray levels (range of 0 to 255) of the A/D converter and hence determine the gray level contrast in the digitized image.

Camera voltage levels between 0 (pedestal level) and 0.714 are digitized to gray levels between 0 and 255. This corresponds to B=0 and W=255.

Dark Signal Correction

The measurement parameter used in the present invention will be substantially independent of light level only when the dark signal is accounted for and the true image signal is measured.

Thus, the procedure for correcting for dark signal is as follows:

Set B=0 and W=255 and sample the dark signal by blocking the camera lens. Store the dark signal image (with suitable frame averaging to improve the measurement) and store these values in a memory buffer of the same size and format as the image.

After each sample image is digitized, subtract the values of the dark signal image in the memory buffer, point by point, from the pixel values in the sample image.

Control of Illumination Level

As may be seen in Figure 7 and Figures 8A-8B, the computerized image processor 14 is programmed to precisely control the light level illuminating the sample object S. This is accomplished by first setting the analog to digital converter A/D to map the camera voltage range to the full gray level output range. The surface of the sample object S is illuminated with the light source 40, with the light source being set to an initial output level. A digitized frame-averaged image of the surface is created by first imaging the light reflected from the surface onto the photodetector array to create an electrical signal representative of the image. The electrical signal is digitized and frame averaged a predetermined number of times and the frame-averaged representation of the image is stored in the image processor memory. The average gray level in the image is determined and the illumination level of the sample object S is adjusted until the average gray level in the image is at a desired level, typically near the midpoint of the dynamic range of the analog to digital converter.

To accelerate the measurement method the initial illumination level is set by initially setting the light source output level to the level used for the previous sample and the illumination adjusting step is first performed using a binary search method to set the light source output level within a predetermined range of light levels. If the desired average gray level is not achieved, the illumination adjusting step is then performed using a binary search method to set the light source output level over the full range of light levels.

Analysis Method

With the full voltage range of A/D voltages selected (Black Reference level = 0, White Reference level = 255), the illumination system is turned off so that no light reaches the CCD array. The image produced by the photodetector array in the camera in the absence of light, known as

the "dark response" or "dark current" image, is digitized a predetermined number of times (typically 64 or 128) and then frame averaged. That is, the corresponding picture elements, or pixels, in each of the images are added and then divided by the number of images digitized to produce an image which represents the average dark current response of the CCD array and its associated electronics. This so called "average dark current" image is stored in memory 14R, such as RAM or in magnetic storage media 14M, for subsequent use.

The average dark current image can be used to correct each pixel in the sample image as follows. This dark current image is stored in memory and subsequently subtracted from each sample image.

For each type of paper, i.e., each set of samples, an "infinite stack" of unprinted sheets is used to establish a predetermined light level . (see Figure 4). This light level is automatically set so the camera output voltage to the A/D converter for the "infinite stack" of sheets is such that the average gray level in the image is in a predetermined range, such as the range 150 +/-10. The digital to analog (D/A) portion of interface board 120 in the computer 14 provides a reference voltage input to the light level controller 44. The light level produced by the light emitting diodes is sensed by the photodetector 48 and the photodetector signal is fed to the light level controller 44 and is compared to the reference voltage to automatically control the light level.

Each sample image is frame averaged a predetermined number of times (typically 64) and the dark current frame-averaged image is then subtracted from it on a pixel by pixel basis to produce a "dark current corrected image".

Region of Interest

The system of the present invention also has the capability to restrict measurement on a sample to a region of interest (ROI) within the field of view. The ROI is specified by the user interactively through placement of a cursor box, which is displayed superimposed on an image of the sample, that is moved and sized by pressing appropriate keys on

the terminal input device to the image processor 14. In the standard analysis method, the entire image is measured.

Operation of the Apparatus

Overall operation of the apparatus is shown in Figure 7. The user specifies the number of samples (also known as replicates) to be measured. Before a measurement of a first sample is performed, the user is prompted to insert a white reference in the instrument. The white reference is a stack of unprinted papers of the same type as the sample papers. The illuminator intensity is set so that the average gray level in the white reference image is at a predetermined level, say 150. This gray level is fixed once for all samples and this level must be attainable by the darkest sample that would be encountered. The light control circuit parameter required to achieve this light setting is stored by the program for use with all samples that are associated with this white reference. The image of the white reference is acquired at this light setting, using frame averaging. The previously acquired dark reference image is subtracted, pixel-by-pixel, from the white reference image to create a corrected white reference image.

When analyzing each replicate sample, the light level is returned to the level used with the white reference by using the stored light control circuit parameter. The sample image is acquired at this light level, using frame averaging. The previously acquired dark reference image is subtracted, pixel-by-pixel, from the sample image to create a corrected sample image. Then, for each pixel, the ratio of the corrected sample gray level to the corrected white reference gray level is calculated. These ratio values are then averaged over all pixels (R). The Digital Showthrough Value, DSV, is 100*(1-R).

The photodetector 48 is positioned within the hemispherical reflector 22D and is interfaced to an electronic circuit to control the illumination level at a constant brightness. This optical feedback insures that the illumination level is precisely constant level once a particular setting is made. The output of the photodetector 48 is stored in the system computer to insure the ability to return to the same light level with

a high degree of accuracy. This prevents drifting of the light level that would adversely affect the Showthrough measurement.

EXAMPLE

The method of the invention was used to characterize a set of coated groundwood paper samples. Monthly printing trials were made using paper supplied by six different paper mills. Samples were printed on the same piece of printing equipment. The same images were printed on paper from all six sources for each monthly production run to facilitate paper quality comparisons.

To quantify the showthrough of the printed image, a black image was printed on the samples on the reverse side from the side to be measured. The side to be measured had no printed image, (i.e., the side to be viewed was white). Each trend line in Figure 9 represents one printing trial or one month's data. These trend lines vary, but appear to be generally consistent.

The plot of Figure 9 illustrating the relationship between opacity and DSV was generated from data in Table 1. The correlation between DSV and opacity is not very high, since the calculation is different and the size of the area being tested is much larger for DSV than for the T-425 method discussed below. The present method captures an image of a rectangular area of about 2.58 inches by 2.0 inches, while the industry standard opacity measurement T-425 makes a single measurement using a 9.53 mm (0.375 inch) circular opening. Thus, the present invention measures an area almost fifty times larger than the standard opacity measurement.

Table 1

DSV	Opacity
11.40	88.00
12.60	87.91
12.90	87.10
12.50	86.69
12.40	88.31
9.90	89.39
17.30	87.16
15.40	88.87
16.10	87.74
15.90	87.8
16.30	87.85
14.50	88.58
14.80	87.56
18.50	86.96
16.20	88.51
18.00	87.24
15.30	88.43
15.20	88.91

Measurement of opacity is in accordance with Technical Association of the Pulp and Paper Industry (TAPPI) standard T-425 om 01, entitled "Opacity of Paper (15/d Geometry, Illuminant A/2 Degrees, 89% Reflectance Backing and Paper Backing)": "the specimen opening shall be round with a diameter of 14.8 +/- 0.25 mm (0.584 +/-0.010 in). The illuminated area shall be circular with a diameter of 9.53 +/- 0.38 mm (.375 +/- 0.015 in) and centered in the specimen opening. " In the experimental measurement, opacity was measured three times and the reported values represent the mean of these three measurements.

Figure 10 shows a plot of the total instrument spectral response (camera sensor, IR-cut filter at sensor (part of CCD array) and green filter). The green filter is chosen so that the total instrument spectral response closely matches the photopic response, the response of the human eye. Thus, measurements made using the present invention should correlate well with observations of human observers. For measurement of visual uniformity of white surfaces U.S. Patent 6,438,256 established that the major limitation in correlating measured results to the

visual ratings was the rather high standard deviations of the human visual ratings.

CLAIMS

1. A method for measuring the degree to which a printed image on a first side of a sheet is visible when illuminating and viewing a second side of the sheet, the method comprising:

a) creating a calibration image of a reference object containing no image;

b) determining an average gray level of the reference object and adjusting the illumination level to achieve a predetermined average gray level;

c) illuminating the sheet at an illumination level the same as that used to create the calibration image and creating an image of the sheet;

d) measuring the ratio of the pixel intensities of the image of the sheet with the corresponding pixel intensities of the calibration image;

e) calculating a mean value of the ratios of the pixel intensities.

2. An improved image analysis method for characterizing the showthrough of a printed image on the reverse surface of a substantially planar sample object having a reflective front surface, by measuring the optical reflectance of the front surface, the method comprising the steps of:

(a) creating a frame-averaged dark current image representing the response of the photodetector array in the absence of light;

(b) uniformly illuminating, with a diffuse light source, the front surface of a reference object, said reference object having no image on its reverse, and creating a calibration image of the reference object, comprising the steps of ;

(1) illuminating the front surface of a reference object with the diffuse light source, the output of the light source being set to an initial illumination output level;

(2) creating a frame-averaged image of the front surface of the reference object;

(3) determining the average gray level in the image of the reference object;

(4) adjusting the illumination level by adjusting the output of the light source and repeating steps (2) and (3) until the average light level reflected by the front surface of the reference object causes an average gray level in the image of step (2) to be within a predetermined range of a predetermined value within the dynamic range of the analog to digital converter, thereby establishing a predetermined illumination level;

(5) creating a frame-averaged reference image of the front surface of the reference object;

(6) creating a dark-current corrected calibration image of the reference object by subtracting the frame-averaged dark current image of step (a) from the frame-averaged reference image of step (5) on a pixel by pixel basis and storing the resulting image in the memory;

(c) uniformly illuminating, with the diffuse light source at the predetermined illumination level, the front surface of a sample object having a printed image on the reverse surface;

(d) creating a frame-averaged image of the front surface of the sample object;

(e) creating a dark-current-corrected image of the front surface of the sample object by subtracting the frame-averaged dark current image of step (a) from the frame-averaged image of step (d) on a pixel by pixel basis and storing the resulting image in the memory; and

(f) analyzing the dark-current-corrected frame-averaged image by calculating the ratio of the image of step (e) with the image of step (b) (6) on a pixel by pixel basis to quantify showthrough.

3. The method of Claim 2, wherein the step (b) (2) and step (d) of creating the frame-averaged image of the surface of the sample object each comprise the steps of:

(1) imaging the light reflected from the front surface onto a photodetector array to create an electrical signal representative of the image;

(2) digitizing the electrical signal using an analog to digital converter;

(3) frame averaging the electrical signal a predetermined number of times;

(4) storing the frame-averaged digitized representation of the image as an array of picture elements in a memory.

4. The method of claim 2, wherein the analyzing step (f) comprises the steps of:

(1) calculating a ratio of the image of step (c) with the image of step (b) (6) on a pixel by pixel basis;

(2) calculating a mean value of the ratios of the pixels; and

(3) subtracting the mean value from the value 1.0 to create a quantitative representation of showthrough.

5. The method of Claim 2, further comprising an optical filter in combination with the lens and the photodetector array, so that the overall spectral response of the combination is such that the image analysis method utilizes information in a predetermined spectral region.

6. The method of Claim 5, further comprising an optical filter being positioned between the lens and the photodetector array, so that the overall spectral response of the combination is such that the image analysis method utilizes information in a spectral region that approximates the photopic response of the human eye.

7. The method of Claim 2, wherein the illumination adjusting step (b) (4) is performed using a binary search method within a predetermined range of light levels.

8. The method of Claim 2, wherein the illumination adjusting step (b) (4) is performed using a binary search method within the full range of light levels.

9. The method of Claim 2, wherein a region of interest (ROI) in the field of view is selected before performing step (b) through (f).

10. The method of Claim 2, wherein the reference object is comprised of a plurality of objects, each having no image on its reverse, stacked atop one another, such that a change in the number of objects in the stack results in no measurable difference in average gray level in the image of the reference object.

11. The method of Claim 10, wherein the reference object is comprised of a plurality of sheets of paper.

12. The method of Claim 2, wherein the sample object is a sheet of paper.

13. An apparatus for measuring the degree to which a printed image on a first side of a substantially planar sample object is visible when illuminating and viewing a second side of the substantially planar sample object, the apparatus comprising:

a) a light tight enclosure comprising a sample object holder, an illuminating assembly for diffusely illuminating the sample object, and an imaging assembly,

b) a computerized image processing assembly for controlling the illumination level of the sample object created by the illuminating assembly and for receiving images created by the imaging assembly and analyzing those images, wherein

(1) the sample object holder comprises a support frame and a support platen for holding the sample object to be measured in a predetermined plane,

(2) the illuminating assembly comprises:

(i) a hemispherical reflector positioned adjacent the sample holder so that the predetermined sample plane corresponds to the equatorial plane of the hemisphere, the hemisphere having a diffusely reflecting interior surface and a polar opening for mounting the imaging assembly,

(ii) a circular array of light sources positioned above the equatorial plane and arranged to illuminate the diffusely reflecting interior surface of the hemisphere;

(iii) a photodetector positioned adjacent the array of light sources light emitting diodes and oriented to sense the level of light diffusely reflected from the interior surface of the hemisphere;

(3) the imaging assembly comprising:

(i) a lens,

(ii) a photodetector array, the lens focussing an image of the object onto the photodetector array, each photodetector in the array creating an electrical signal representative of the light reflected from the front surface of the object, the photodetector array being connected to the computerized image processing assembly.

14. The apparatus of claim 13, wherein each light source comprises a white light emitting diode.

15. The apparatus of claim 13, further comprising an optical filter in combination with the lens and the photodetector array, the filter having a spectral response such that the overall spectral response of the apparatus is a predetermined spectral response.

16. The apparatus of claim 15, further comprising an optical filter being positioned between the lens and the photodetector array, so that the overall spectral response of the apparatus approximates the photopic response of the human eye.

17. The apparatus of claim 13, wherein the interior surface of the hemisphere has a substantially non-reflecting region adjacent the polar opening so that specular reflections from the object are not imaged by the imaging assembly.

18. The apparatus of claim 13, wherein the interior surface of the hemisphere has a substantially non-reflecting region adjacent the polar opening corresponding to the area of the sample object being imaged.

TITLE OF INVENTION

METHOD AND APPARATUS FOR QUANTIFYING VISUAL SHOWTHROUGH OF PRINTED IMAGES ON THE REVERSE OF PLANAR OBJECTS

ABSTRACT

An improved image analysis method to quantify visual showthrough of printed images on the reverse face of planar objects, such as paper. An illumination level is set using a white reference object. A white reference image is stored in a computer memory. An image of a planar object having a printed image on the reverse face is stored in a computer memory. A pixel by pixel ratio of the two images is calculated and a mean value of the ratios is calculated to characterize the visual showthrough. The measurements are substantially independent of both the image shading and the overall lightness differences among the objects within a sample group.

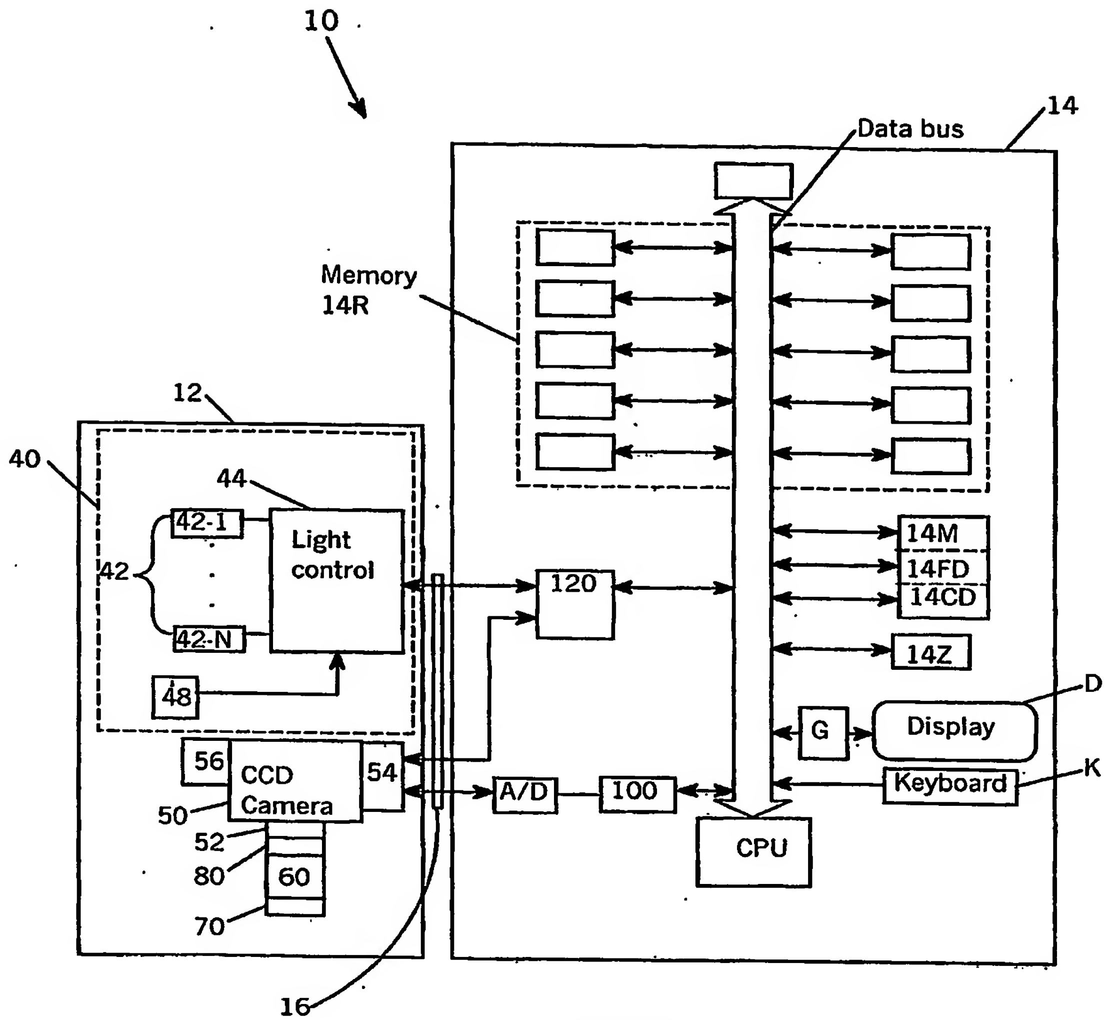

10
14
Data bus
Memory
14R
12
40
44
42-1
Light
control
42
42-N
48
120
14M
14FD
14CD
14Z
D
G
Display
56
CCD
Camera
54
A/D
100
Keyboard
K
50
52
80
60
70
CPU
16

Figure. 1

Figure 2

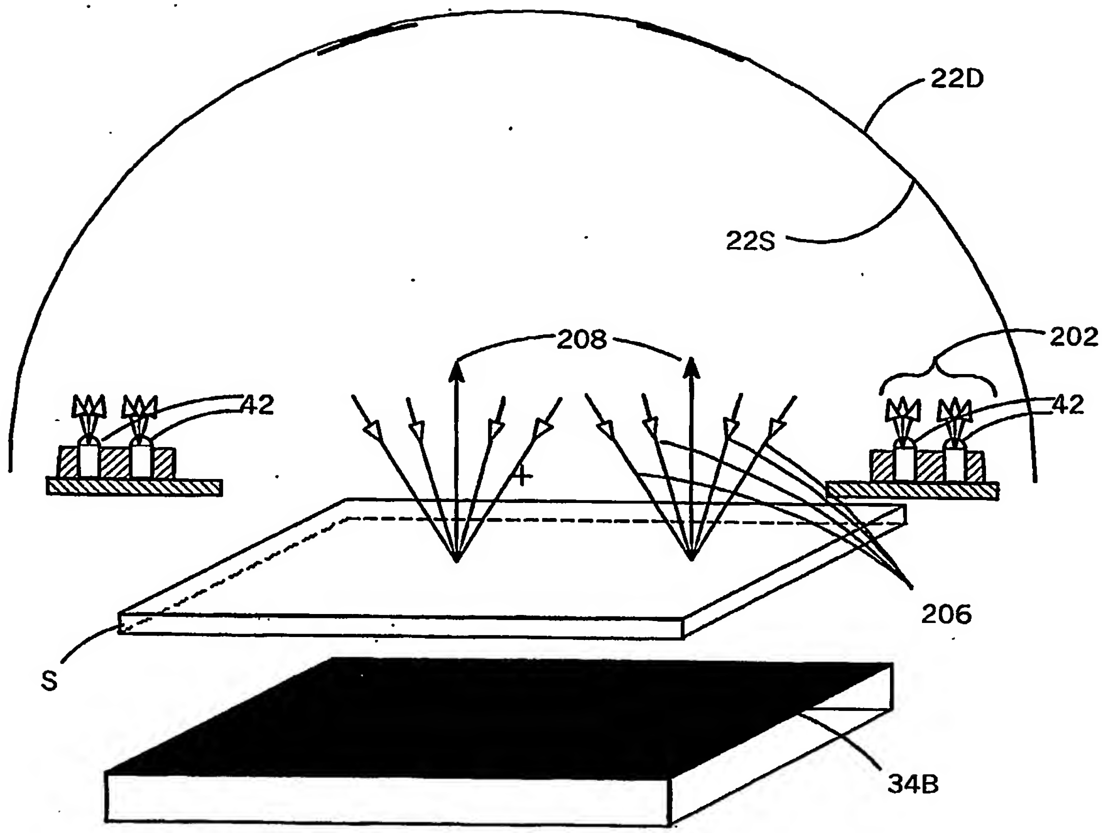


Figure 3A

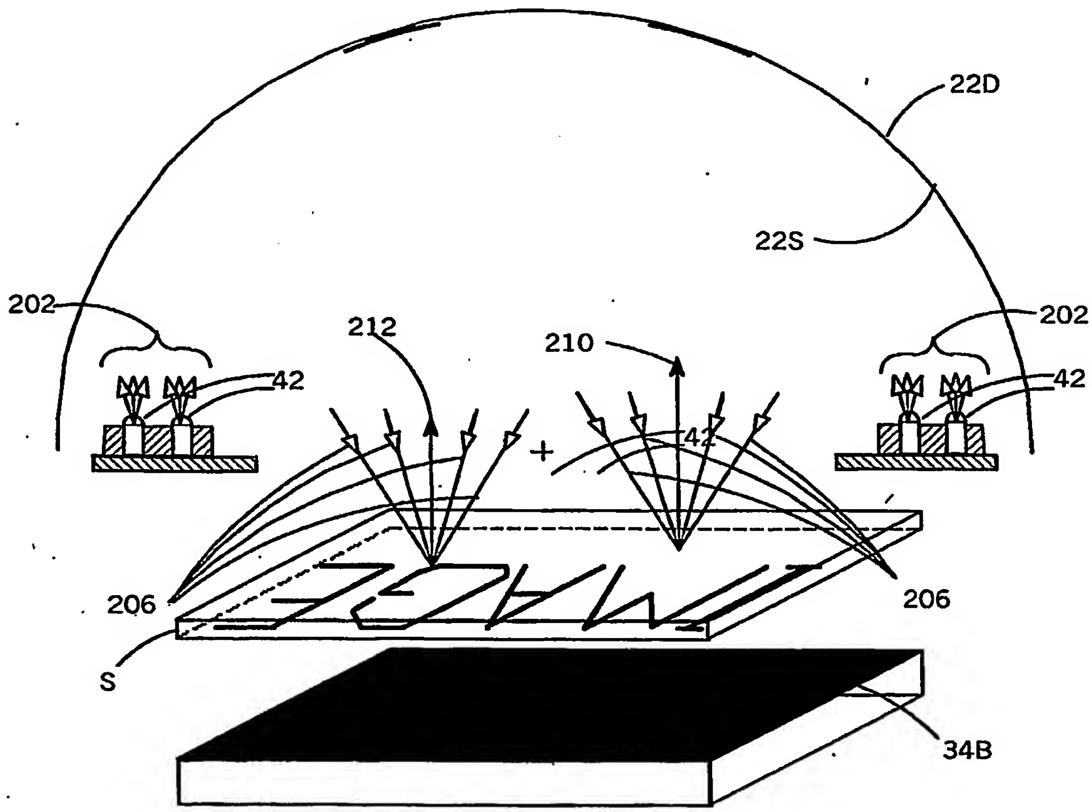


Figure 3B

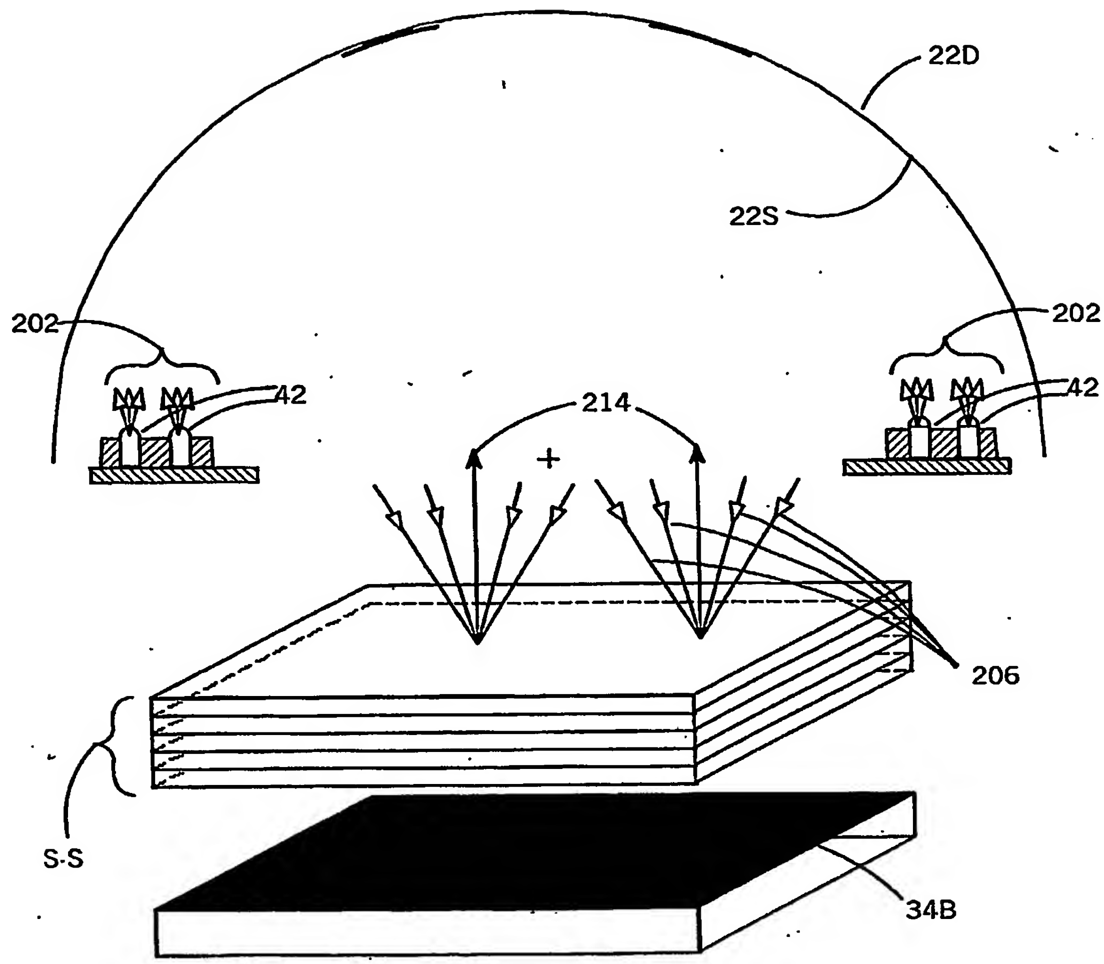


Figure 4

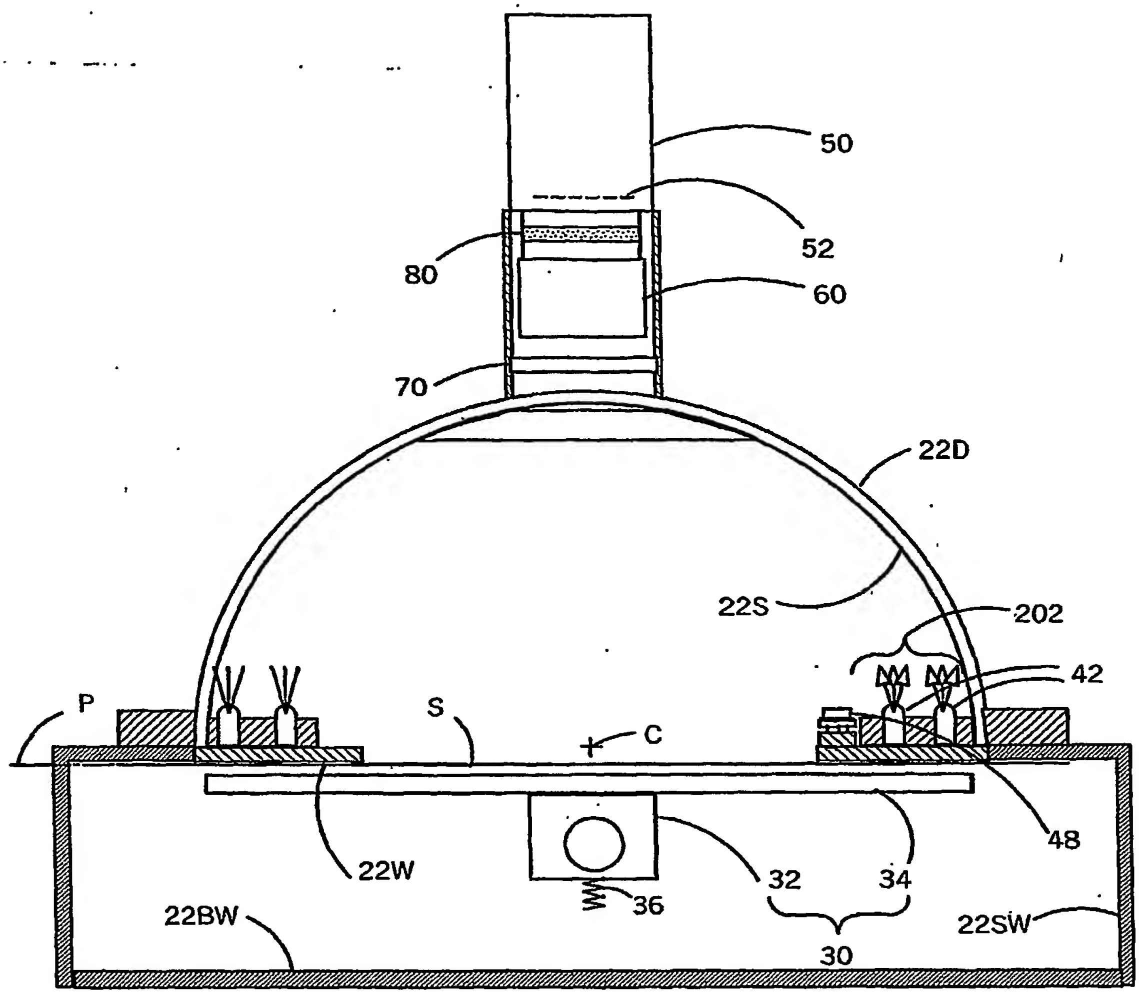


Figure 5A

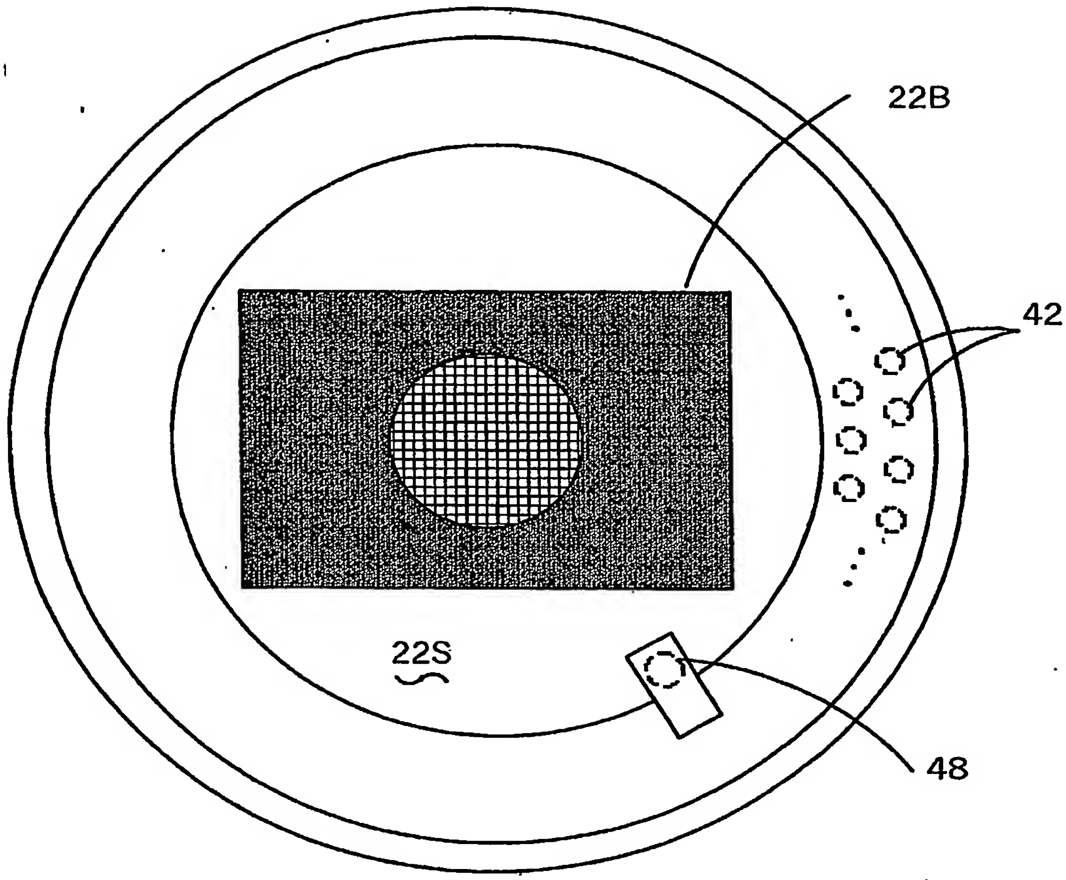


Figure 5B

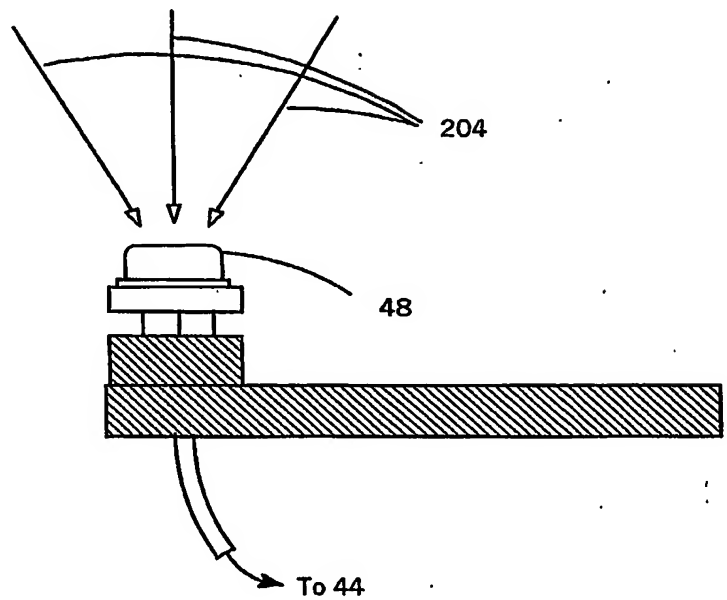


Figure 6

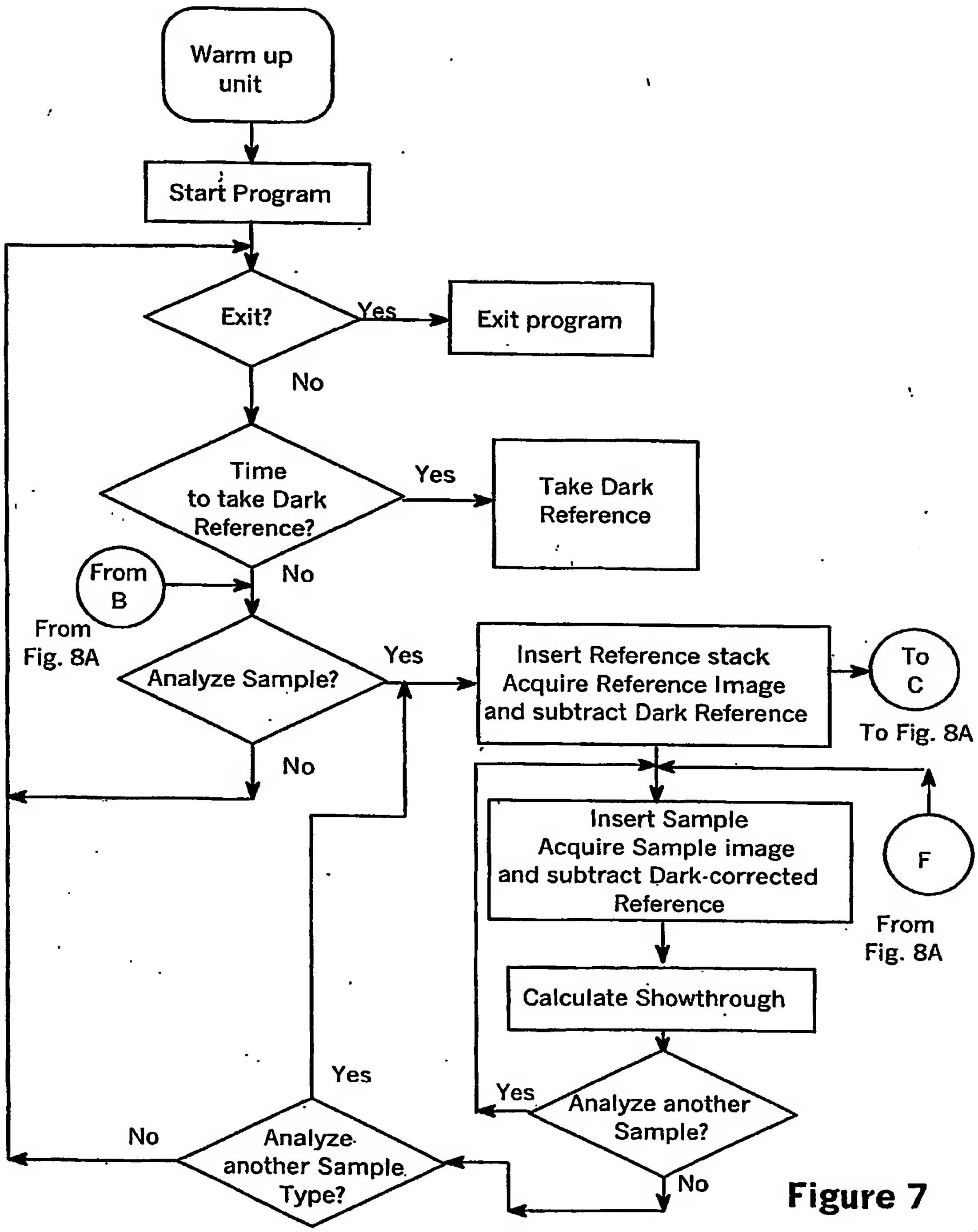
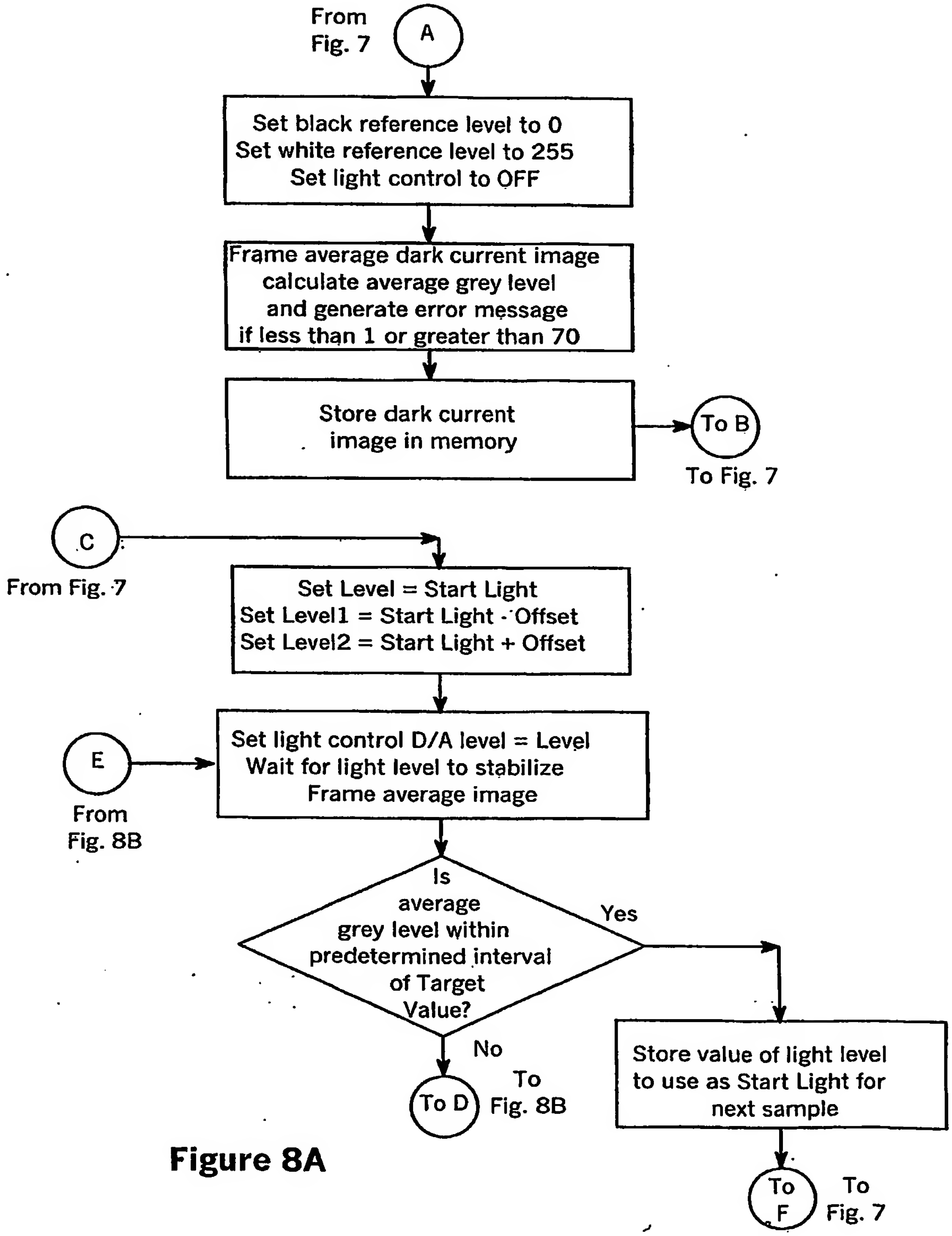

Warm up unit
Start Program
Exit?
Yes
Exit program
No
Time to take Dark Reference?
Yes
Take Dark Reference
No
From B
From Fig. 8A
Analyze Sample?
Yes
Insert Reference stack Acquire Reference Image and subtract Dark Reference
To C
To Fig. 8A
No
Insert Sample Acquire Sample image and subtract Dark-corrected Reference
F
From Fig. 8A
Calculate Showthrough
Yes
Yes
Analyze another Sample?
No
Analyze another Sample Type?
No

Figure 7



From Fig. 7
A
Set black reference level to 0
Set white reference level to 255
Set light control to OFF
Frame average dark current image calculate average grey level and generate error message if less than 1 or greater than 70
Store dark current image in memory
To B
To Fig. 7
C
From Fig. 7
Set Level = Start Light
Set Level1 = Start Light - Offset
Set Level2 = Start Light + Offset
E
From Fig. 8B
Set light control D/A level = Level
Wait for light level to stabilize
Frame average image
Is average grey level within predetermined interval of Target Value?
Yes
No
To D
To Fig. 8B
Store value of light level to use as Start Light for next sample
To F
To Fig. 7

Figure 8A

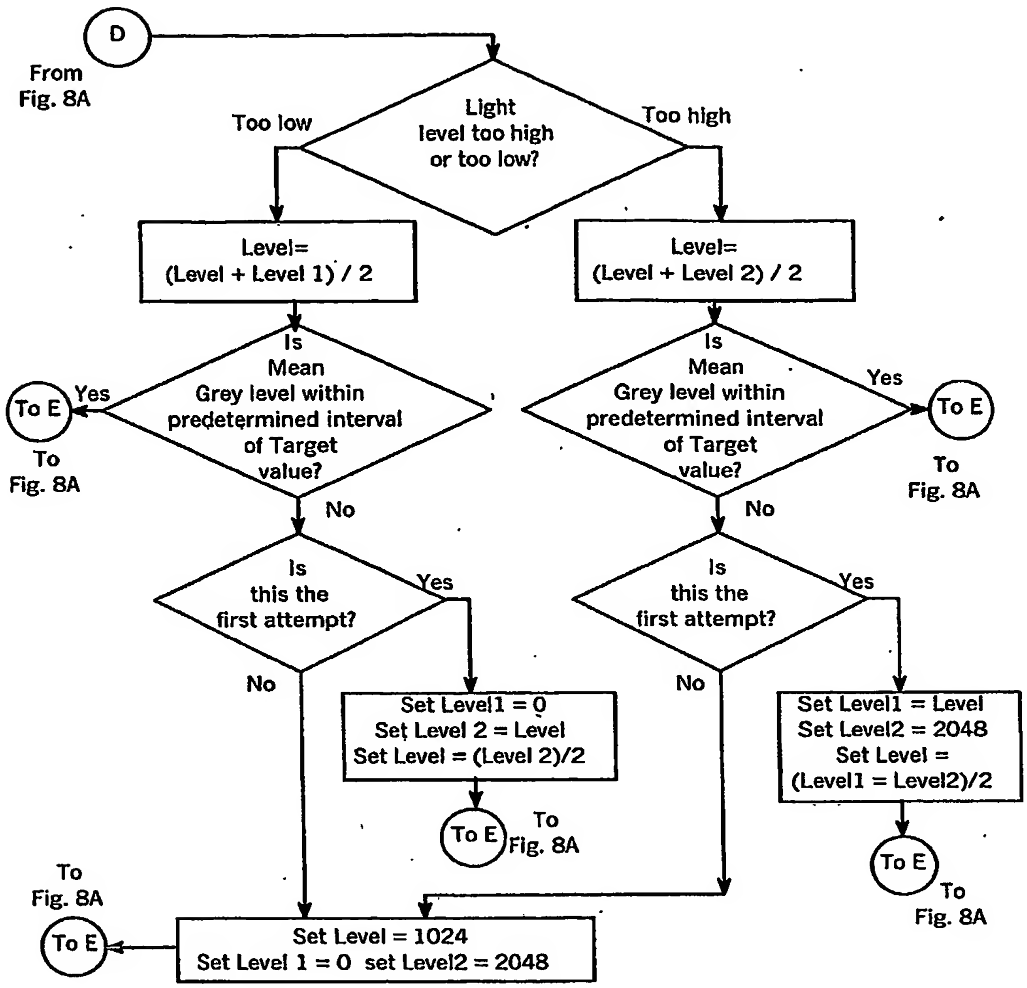

D
From
Fig. 8A
Light
level too high
or too low?
Too low
Too high
Level=
(Level + Level 1) / 2
Level=
(Level + Level 2) / 2
Is
Mean
Grey level within
predetermined interval
of Target
value?
Yes
To E
To
Fig. 8A
No
Is
Mean
Grey level within
predetermined interval
of Target
value?
Yes
To E
To
Fig. 8A
No
Is
this the
first attempt?
Yes
No
Set Level1 = 0
Set Level 2 = Level
Set Level = (Level 2)/2
To E
To
Fig. 8A
Is
this the
first attempt?
Yes
No
Set Level1 = Level
Set Level2 = 2048
Set Level =
(Level1 = Level2)/2
To E
To
Fig. 8A
To
Fig. 8A
To E
Set Level = 1024
Set Level 1 = 0 set Level2 = 2048

Figure 8B

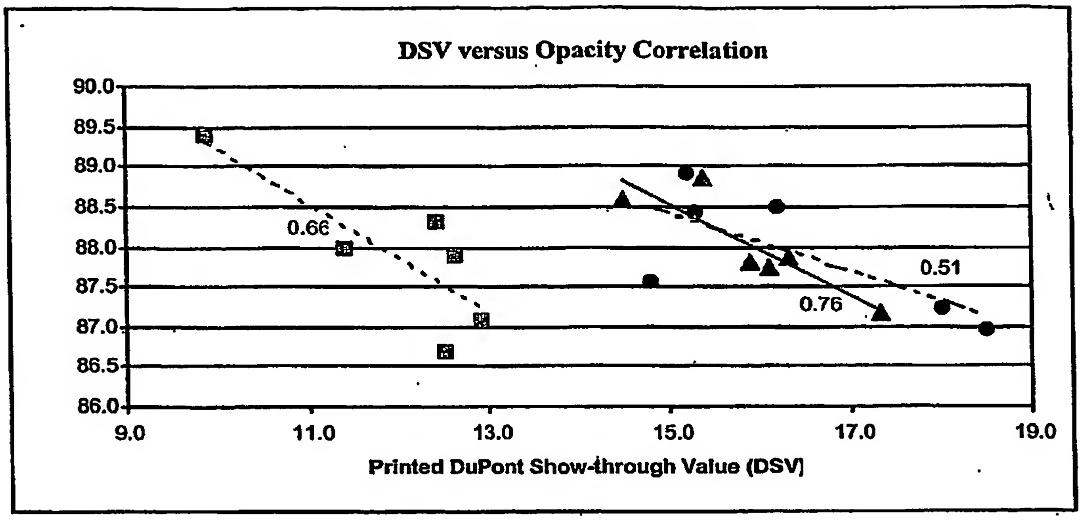

DSV versus Opacity Correlation
90.0
89.5
89.0
88.5
88.0
87.5
87.0
86.5
86.0
9.0
11.0
13.0
15.0
17.0
19.0
0.66
0.51
0.76
Printed DuPont Show-through Value (DSV)

Figure 9

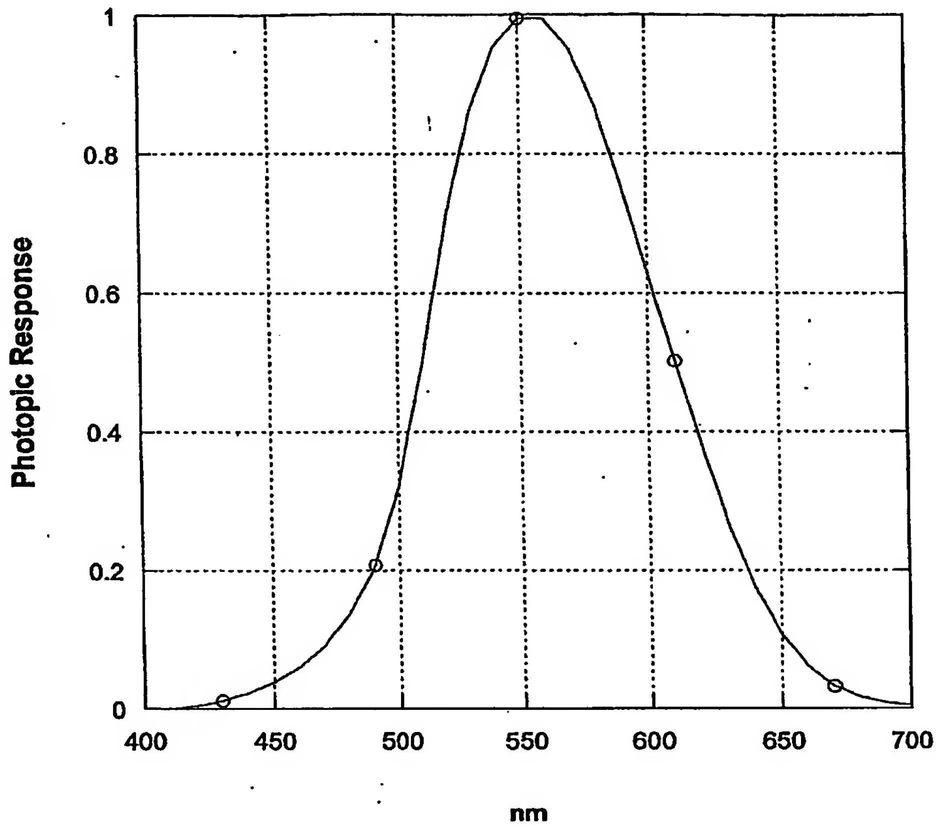


Figure 10